Milestones

Three major developments are responsible for rejuvenation of optics & its application in modern technology:

1- Invention of Laser

2- Fabrication of low-loss optical Fiber

3- Development of Semiconductor Optical Device

Basic fiber optic system model

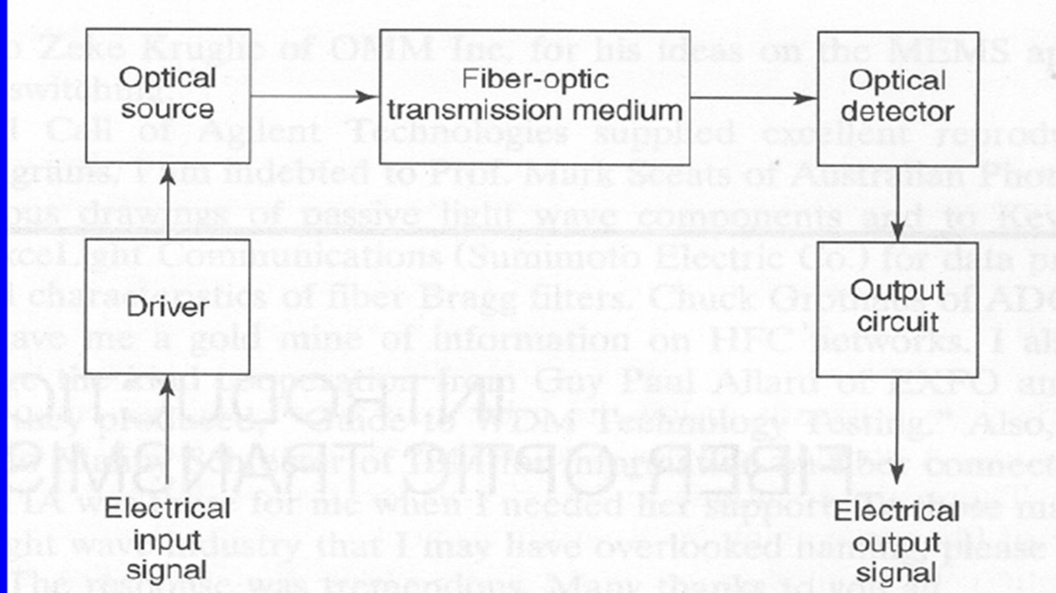

Figure 1.1. A simplified fiber-optic communication link model.

Unit

- Decibels (dB) – ratios or relative units

In designing and implementing an optical fiber link, it is convenient to reference the signal level either to some absolute value or to a noise level.

Power ratio in dB = $10 \log \frac{P_2}{P_1}$

P_1 and P_2 are optical powers in mW

Examples of decibel measures of power ratios

Power ratio	10^N	10	2	1	0.5	0.1	10^{-N}
dB	$+10N$	+10	+3	0	−3	−10	$-10N$

Unit

- The dBm – absolute value

Decibel power level referred to 1 mW

Power level = $10 \log \frac{P_1}{1mW}$

Examples of dBm units (decibel measure of power relative to 1 mW)

Power (mW)	100	10	2	1	0.5	0.1	0.01	0.001
Value (dBm)	+20	+10	+3	0	−3	−10	−20	−30

Examples

- 3dB loss

$$-3dB = 10\log(\frac{P_2}{P_1})$$

$$\frac{P_2}{P_1} = 10^{-3/10} \approx 0.5$$

- 200 μW in dBm unit

$$P = 10\log[\frac{P(W)}{1mW}] = 10\log[\frac{200\times10^{-6}W}{1\times10^{-3}W}] = -7.0dBm$$

Fiber-optic communication

- is a method of transmitting information from one place to another by sending light through an optical fiber.
- The light forms an electromagnetic carrier wave that is modulated to carry information.

The process of communicating using fiber-optics involves the following basic steps:

- Creating the optical signal using a transmitter,
- relaying the signal along the fiber, ensuring that the signal does not become too distorted or weak,
- and receiving the optical signal and converting it into an electrical signal.

OPTICAL FIBER

- An **optical fiber** (or **fibre**) is a glass or plastic fiber that carries light along its length.
- Light is kept in the "core" of the optical fiber by total internal reflection.

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Advantages of Optical Fibre

- Thinner
- Less Expensive
- Higher Carrying Capacity
- Less Signal Degradation& Digital Signals
- Light Signals
- Non-Flammable
- Light Weight
- greater capacity (bandwidth up to 2 Gbps, or more)
- smaller size and lighter weight
- lower attenuation
- immunity to environmental interference
- highly secure due to tap difficulty and lack of signal radiation

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DisAdvantages of fiber optics

- Disadvantages include the cost of interfacing equipment necessary to convert electrical signals to optical signals. (optical transmitters, receivers) Splicing fiber optic cable is also more difficult.
- expensive over short distance
- requires highly skilled installers
- adding additional nodes is difficult

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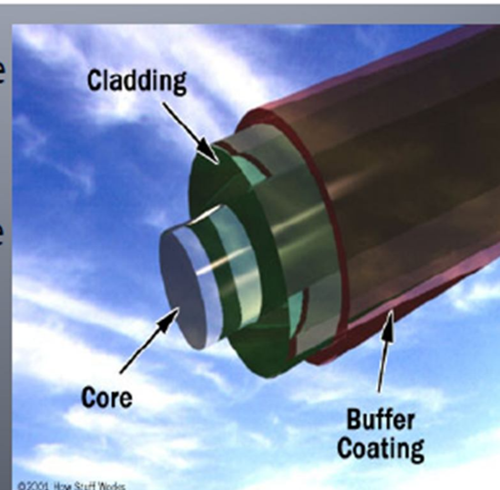
Fiber Optic Cable & Areas of Application

- relatively new transmission medium used by telephone companies in place of long-distance trunk lines
- also used by private companies in implementing local data networks
- require a light source with injection laser diode (ILD) or light-emitting diodes (LED)
- fiber to the desktop in the future

OPTICAL FIBER CONSTRUCTION

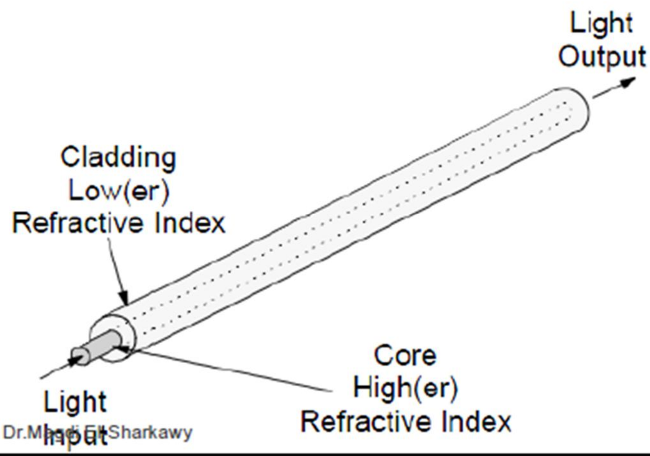
Optical fiber consists of a core, cladding, and a protective outer coating, which guides light along the core by total internal reflection.

Core – thin glass center of the fiber where light travels.
Cladding – outer optical material surrounding the core
Buffer Coating – plastic coating that protects the fiber.



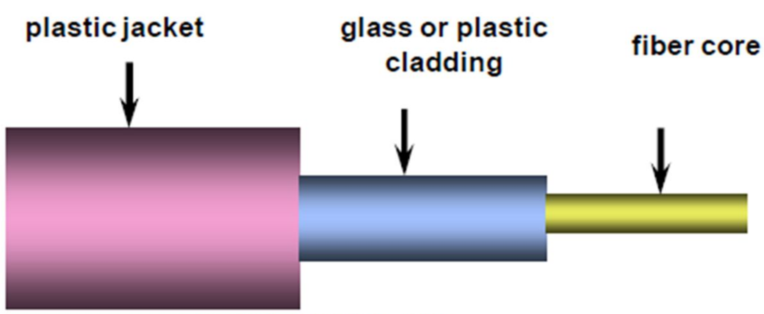
OPTICAL FIBER

- The core, and the lower-refractive-index cladding, are typically made of high-quality silica glass, though they can both be made of plastic as well.

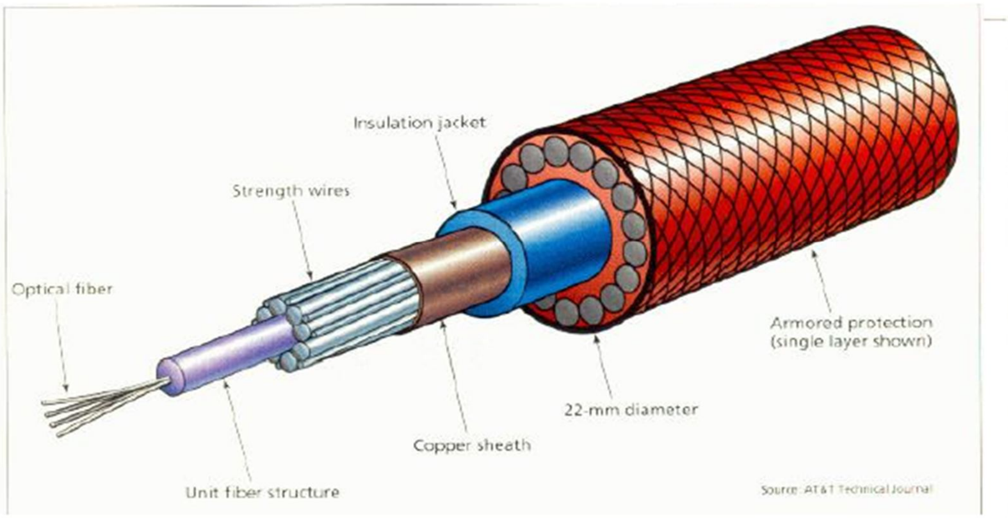


Fiber Optic Layers

- consists of three concentric sections



Fiber Optic Cable



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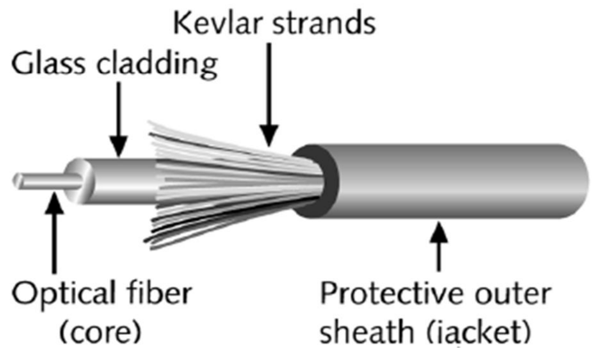
Fiber-Optic Cable

- Contains one or several glass fibers at its core
- Surrounding the fibers is a layer of glass called cladding



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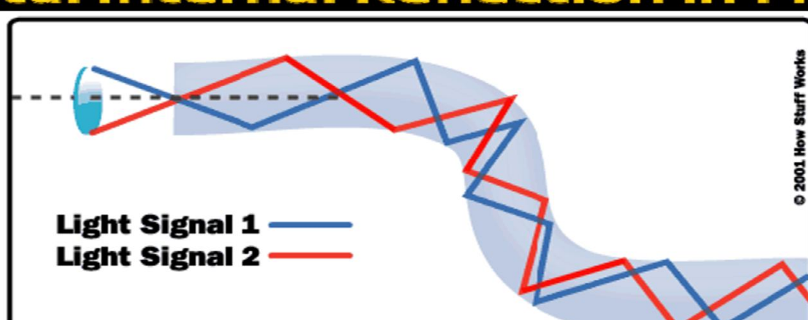
Total Internal Reflection in Fiber



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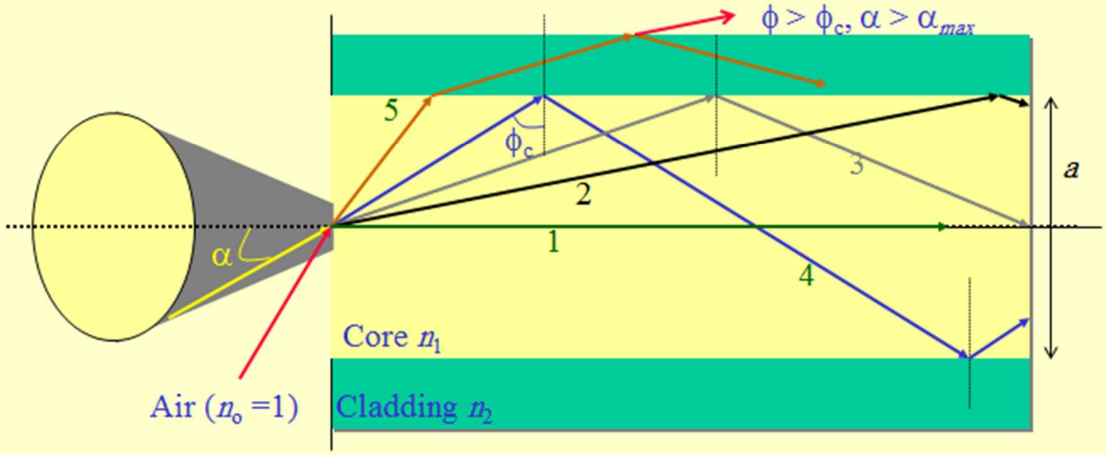
Ray Propagation in Fibre - *Bound Rays*



From Snell's Law: $n_0 \sin\alpha = n_1 \sin(90 - \phi)$

$\alpha = \alpha_{max}$ when $\phi = \phi_c$ **Thus,** $n_0 \sin\alpha_{max} = n_1 \sin\phi_c$

Or $n_0 \sin\alpha_{max} = n_1 (1 - \sin^2\phi_c)^{0.5}$

Since $\phi_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

Then $n_0 \sin\alpha_{\max} = n_1\left[1-\left(\frac{n_2}{n_1}\right)^2\right]^{0.5} = \left[n_1^2 - n_2^2\right]^{0.5}$

$\left[n_1^2 - n_2^2\right]^{0.5} = Numerical\ Aperture\,(NA)$

NA determines the light gathering capabilities of the fibre

Therefore $n_0 \sin\alpha_{max} = \mathrm{NA}$

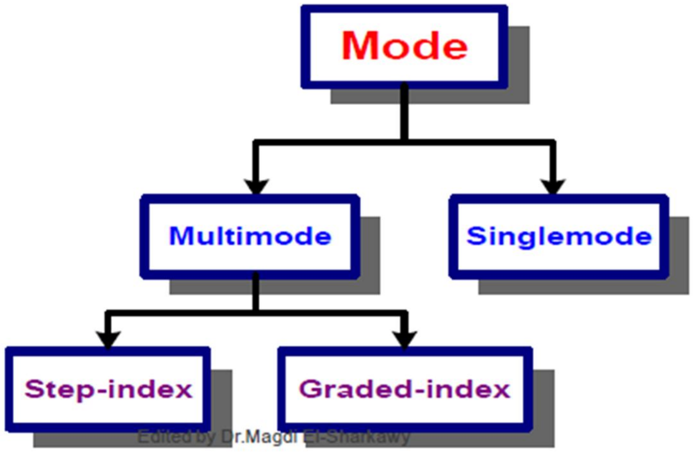
Fibre acceptance angle $\alpha_{\max} = \sin^{-1}\left(\frac{NA}{n_0}\right)$

Note $\frac{n_1 - n_2}{n} = \Delta$ Relative refractive index difference

Thus $NA = n_1(2\Delta)^{0.5}$ $0.14 < \mathrm{NA} < 1$

MODE OF PROPAGATION

- Two main categories of optical fiber used in fiber optic communications are multi-mode optical fiber and single-mode optical fiber.



- A fiber can support:
  - many modes (multi-mode fibre).
  - a single mode (single mode fiber).
- The number of modes (V) supported in a fiber is determined by the indices, operating wavelength and the diameter of the core, given as.

$$V = \frac{2\pi}{\lambda} a \sqrt{n_c^2 - n_{cl}^2} \quad \text{or} \quad V = \frac{2\pi a}{\lambda} NA$$

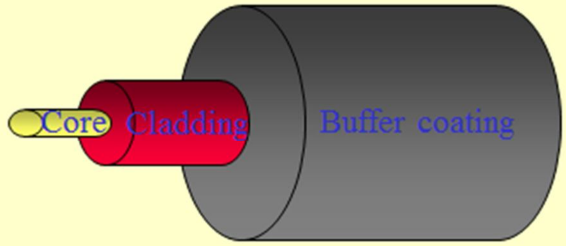
- V<2.405 corresponds to a single mode fiber.
- By reducing the radius of the fiber, V goes down, and it becomes impossible to reach a point when only a single mode can be supported.

Total number of guided modes M for multi-mode fibres:

Multi-mode SI $M = 0.5V^2$ Multi-mode GI $M \approx 0.25V^2$

Basic Fibre Properties

- Cylindrical
- Dielectric
- Waveguide
- Low loss
- Usually fused silica
- Core refractive index > cladding refractive index
- Operation is based on total internal reflection



SINGLE-MODE FIBERS

- **Single-mode fibers –** used to transmit one signal per fiber (used in telephone and cable TV). They have small cores(9 microns in diameter) and transmit infra-red light from laser.
- Single-mode fiber's smaller core (<10 micrometres) necessitates more expensive components and interconnection methods, but allows much longer, higher-performance links.

MULTI-MODE FIBERS

- **Multi-mode fibers** – used to transmit many signals per fiber (used in computer networks). They have larger cores(62.5 microns in diameter) and transmit infra-red light from LED.
- Multimode fiber has a larger core (≥ 50 micrometres), allowing less precise, cheaper transmitters and receivers to connect to it as well as cheaper connectors.

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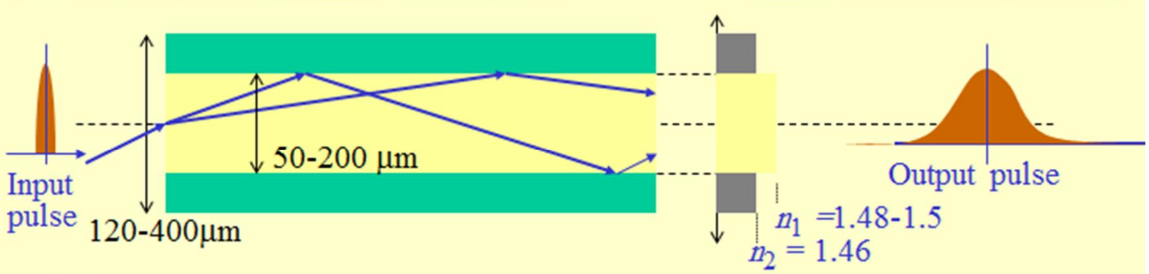
Step-index Multi-mode Fibre



dn=0.04,100 ns/km

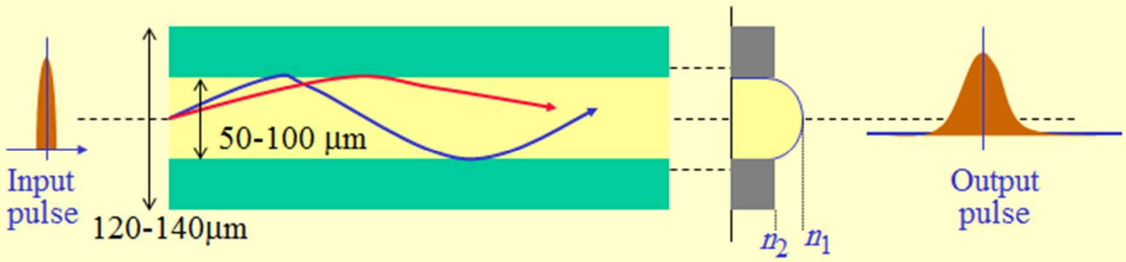
Advantages:

- Allows the use of non-coherent optical light source, e.g. LED's
- Facilitates connecting together similar fibres
- Imposes lower tolerance requirements on fibre connectors.
- Cost effective

Disadvantages:

- Suffer from dispersion (i.e. low bandwidth (a few MHz)
- High power loss

Graded-index Multi-mode Fibre



dn = 0.04,1ns/km

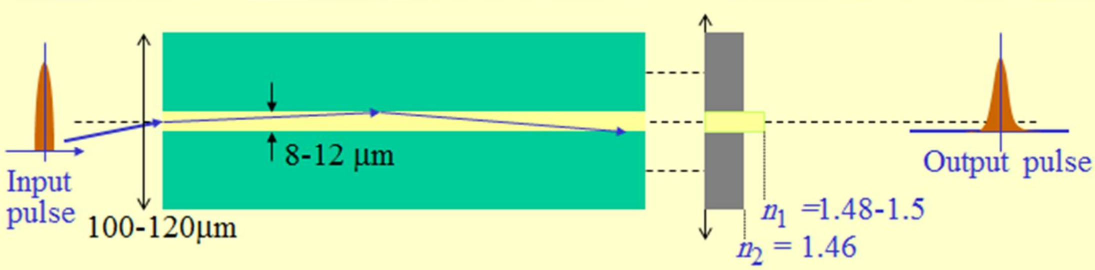
Advantages:

- Allows the use of non-coherent optical light source, e.g. LED's
- Facilitates connecting together similar fibres
- Imposes lower tolerance requirements on fibre connectors.
- Reduced dispersion compared with STMMF

Disadvantages:

- Lower bandwidth compared with STSMF
- High power loss compared with the STSMF

Step-index Single-mode Fibre



dn = 0.005, 5ps/km

Advantages:

- Only one mode is allowed due to diffraction/interference effects.
- Allows the use high power laser source
- Facilitates fusion splicing similar fibres
- **Low dispersion, therefore high bandwidth (a few GHz).**
- Low loss (0.1 dB/km)

Disadvantages:

- Cost